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DEVELOPMENT OF VAULT TOILET WASTE TREATMENT SYSTEMS.(U)
JUN 78 D D KRAYBILL, S R STRUSS
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June 1978
Pollution Abatement Demonstration Projects and Systems Evaluation

LEVEL II

DEVELOPMENT OF VAULT TOILET WASTE TREATMENT SYSTEMS

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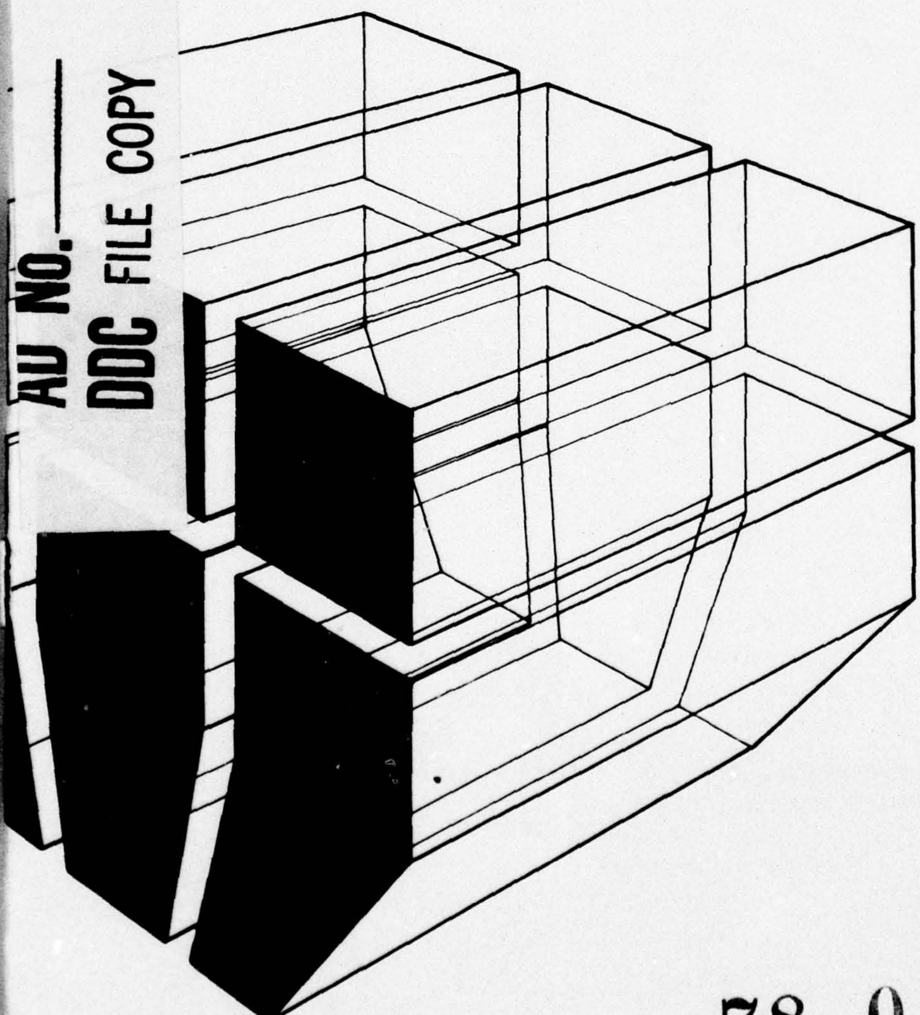

by
D. D. Kraybill
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This interim report describes the study, design, and installation of systems for the in-situ treatment of vault toilet (latrine) wastes. The study investigates properties of vault waste and various waste treatment alternatives. It then selects the most practical alternatives for design and construction. The report then describes design considerations and gives two general overviews of the final designs. The

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treatment systems consist of one mechanical mixer and two compressor-driven bubble aerators, all of which are installed in concrete lined vaults at Fort Polk, LA. Finally, it details the future testing programs for these devices.

FOREWORD

This study was conducted by the Environmental Division (EN) of the U.S. Army Construction Engineering Research Laboratory (CERL) for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A726270A896, "Environmental Quality for Construction and Operation of Military Facilities"; Task T2, "Pollution Abatement Systems"; Work Unit 010, "Pollution Abatement Demonstration Projects and Systems Evaluations." The QCR Number is 1.03.006(3). Mr. A. P. Norwood, DAEN-FEU-S, was the OCE Technical Monitor. Dr. R. K. Jain is Chief of EN.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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DEVELOPMENT OF VAULT TOILET
WASTE TREATMENT SYSTEMS

1 INTRODUCTION

Background

Vault toilets (concrete-lined latrines) are common on isolated sections of military bases, campsites, and at isolated work areas almost everywhere. The wastes deposited at these sites are usually anaerobic and highly concentrated,[1] and generally remain untreated until pumped out and transported to a sewage treatment plant.

There are basically three reasons why this system is undesirable. The first is that the untreated vault waste becomes extremely odorous, making use of the vault unpleasant, and attracting flies, insects, and other vermin.

The second is that the anaerobic waste can impose a shock load on the sewage treatment plant to which it is taken, thus upsetting the treatment processes and reducing effluent quality.

The third undesirable aspect is the cost of pumping the waste. When done under contract, costs have ranged from $60 for emptying, to $150 for emptying and removal of debris. If a large number of vaults are in continuous use, this cost can become considerable.

Thus, it is desirable to devise a method for treating the wastes from vault toilets in situ in order to (1) improve aesthetics and sanitation in the latrines, (2) reduce shock loads to sewage treatment plants when the waste is removed for further treatment, and (3) extend the time between pumping periods by providing some degradation of the wastes while it resides in the vault.

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[1] D. Alleman, S. Senkius, W. Hedstrom, and L. Pochop, "Pilot Plant Treatment of Recreational Vault Toilet Waste," *Journal of the Water Pollution Control Federation (JWPCF)*, Vol 47, No. 5 (February 1975), pp 377-383.

Previous studies[2] indicate that simple bubble aeration can maintain aerobic conditions; studies on livestock waste[3] indicate that on-site treatment by biodegradation may be possible when the wastes are aerated.

Objective

The overall objectives of this study were to: (1) identify possible treatment alternatives, (2) select for further study the alternative which appeared most practical, (3) design, construct, and install the chosen systems, (4) collect data on the systems' operations while under actual use, and (5) evaluate the collected data to determine the usefulness of selected systems, and (6) develop procurement specifications for the systems.

The objective of this report was to detail the findings of objectives (1), (2), and (3) above.

Approach

This study was comprised of (1) a literature survey to investigate properties of vault waste and possibilities for its treatment, (2) sampling of waste to be treated and subsequently design of treatment systems (tests included biochemical oxygen demand [BOD] and oxygen uptake rate [OUR]; the systems selected for design were one mechanical mixer and two bubble aerators), and (3) construction and installation of the selected systems at Fort Polk, LA.

Scope

There were two limitations to this investigation: (1) that all treatment systems be constructed with existing vaults, i.e., no tests would be conducted on new vaults with built-in treatment systems or treatment systems which receive influent from several vaults, and (2) that all treatment systems would require electrical power. This study did not apply to vaults so isolated that some form of electrical power could not be supplied.

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2 D. Alleman, et al., "Pilot Plant Treatment of Recreational Vault Toilet Waste," *Journal of Water Pollution Control Federation (JWPCF)*, Vol 47, No. 2 (February 1975).

3 D. L. Day, D. D. Jones and J. L. Converse, *Livestock Waste Management Studies*, Termination Report, Project No. 331-15-10-375 (University of Illinois, College of Agriculture, Agricultural Engineering Department, July 1970).

Mode of Technology Transfer

No existing document will be impacted. The final report will be issued as an Engineering Technical Note.

2 LITERATURE SURVEY

A literature survey was conducted with the System Development Corporation Search Service (ORBIT), a computerized file searching system. ORBIT reviewed Pollution Abstracts, the National Technical Information Service (NTIS), and Compendix, a machine-readable engineering index. Vault toilets, latrines, and livestock waste processing were the general topics of the information search; it was intended that the retrieved information would help determine the strength of vault waste in terms of biochemical oxygen demand (BOD) and suspended solids (SS), and provide other information which might seem appropriate. Information was also desired about any other proposed treatment systems for vault toilet waste.

Three projects of interest came to light. The first was a University of Illinois study[4] of hog waste treatment in which hogs were housed in sheds with slotted floors. A concrete-lined recirculating ditch (Figure 1) placed under the slots received the hog waste and kept it agitated. On-site inspection by this investigation affirmed that this system was significantly successful in suppressing odor. It was difficult to compare the amount of treatment received in this system to a similar human-waste vault system, however, because this livestock waste system received a more constant flow of waste, and thus better allowed for growth of an appropriate biopopulation.

A second study, published by the U.S. Forest Service in the *Journal of the Water Pollution Control Federation (JWPCF)*,[5] described an experiment to remove waste from vault toilets in the Medicine Bow National Forest and to treat it in a two-stage, aerated pilot lagoon. Because this experiment involved removal of waste, it did not apply directly to this project; however, the article was helpful in that it assigned a BOD and SS value to vault toilet waste--approximately 8,000 to 35,000 mg/L BOD, averaging 19,000 mg/L, and SS averaging 25,200 mg/L. In essence, the reported results of vault-toilet waste properties in the Forest Survey study were highly variable.

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[4] D. L. Day, D. D. Jones, and J. L. Converse; *Livestock Waste Management Studies Termination Report*, Project No. 31-15-10-375 (University of Illinois, College of Agriculture, Agricultural Engineering Department, July 1970).

[5] D. Alleman, S. Jenkins, W. Hedstrom, and L. Pochop, "Pilot Plant Treatment of Recreational Vault Toilet Waste," *Journal of Water Pollution Control Federation (JWPCF)*, Vol 5 (February 1975), pp 377-383.

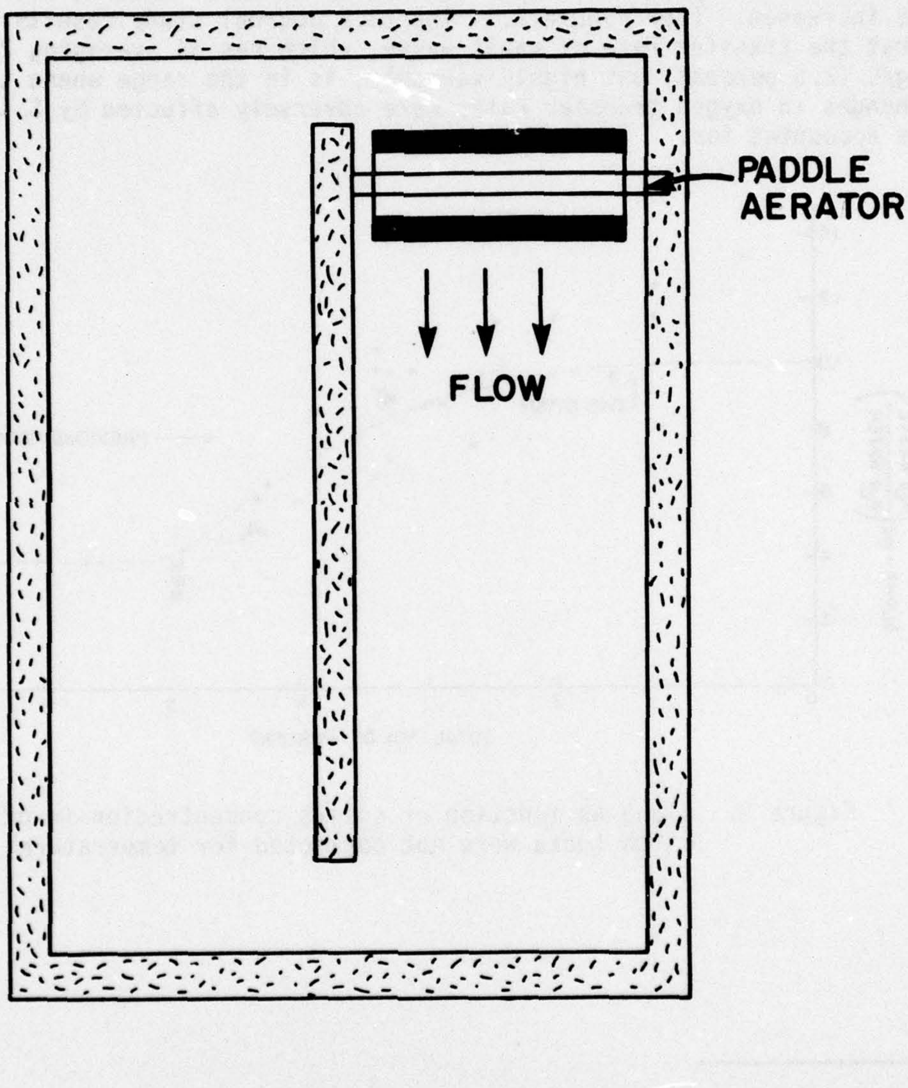

Figure 1. Hog waste treatment system.

A third study, "Oxygen Transfer at High Solids Concentrations," was published in the *American Society of Civil Engineers (ASCE) Journal of the Environmental Engineering Division.*[6] The article first reviewed the basics of oxygen transfer in tap water, then detailed changes in oxygen transfer rates as they related to SS. It also described a number, alpha, which is the transfer rate for wastewater, divided by the transfer rate for tap water. Alpha is related to SS in that it decreased as SS increased. (See Figure 2.) The ASCE Journal study results indicated that the transfer rate of vault waste, which has SS averaging 25,000 mg/L (2.5 percent) but highly variable, is in the range where the changes in oxygen transfer rates were adversely affected by SS and must be accounted for.

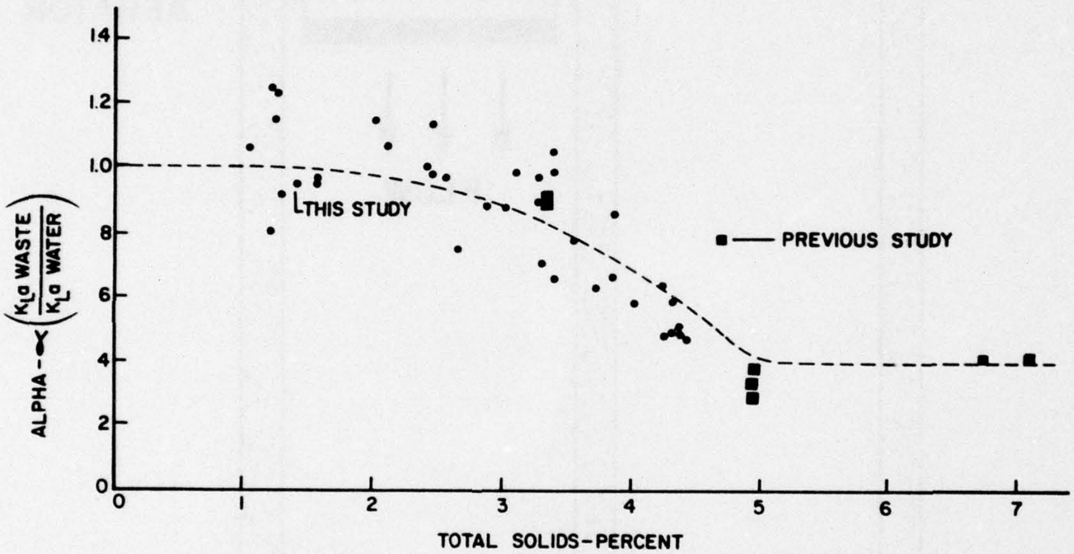

Figure 2. Alpha as function of solids concentration in oxidation ditch (data were not corrected for temperature).

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[6] D. R. Baker, R. C. Loehr, A. L. Anthorisen, "Oxygen Transfer at High Solids Concentrations," *American Society of Civil Engineers (ASCE) Journal of the Environmental Engineering Division*, Vol 101, No. EE5 (October 1975), pp 759-774.

3 ASSESSMENT OF ALTERNATIVE SYSTEMS

Because it was not necessary to treat vault waste completely, the systems considered--composting, incineration, chemical disinfection, mechanical aeration, and bubble aeration--were primarily pretreatment systems which would improve vault conditions while reducing odor and waste volume, thereby reducing pumping costs.

The final criteria for selection were simplicity, suitability to retrofitting existing vaults, and cost. The retrofit was required because vaults presently in use in many training areas are in good condition and do not warrant replacement. Simplicity was necessary to keep operation and maintenance (O&M) labor requirements to a minimum. (A septic tank and drainage field or a small treatment plant would have solved the waste disposal problem; however, the complexity and expense of these systems made them unsuitable for application to vault waste treatment.)

Composting

Composting is a simple, compact, and energy-efficient treatment method that uses bacteria which occur naturally in soil or humis to decompose waste. Air and moderate heat are supplied to the bacteria to aid in decomposition.

Small, single family compost units are presently used extensively in Sweden and have been commercially available in this country since 1974. One such unit* is a self-contained box 3 x 2 x 3 ft (0.9 x 0.6 x 0.9 m) that can treat the waste of five to six persons on a continuous basis. The power required to warm the waste and ventilate the unit averages around 150 Watts, and no water need be added under normal conditions. An annual emptying of a tray which collects a waste residue ash is the only regular maintenance. In addition, water must be added to allow decomposition to continue if the unit is to be unused for 2 weeks or longer. Contaminants such as gasoline, acetone, hot cigarette butts and matches, metal, plastics, glass, and detergents must be avoided because they increase the possibility of fire and can interrupt the biological breakdown of waste.

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*ECOLET, manufactured by Recreation Ecology Conservation of United States, Inc., Milwaukee, Wisconsin.

Although composting appears to be a favorable alternative to vault toilets, the high incidence of contamination common to public vault toilets indicates that this system would be an unsuccessful adaptation for use outside of the private sector. This was demonstrated by this investigation's preliminary survey of the test site at Fort Polk, LA, where samples of waste taken from one of the latrines for analysis revealed cans, bottles, and other debris despite signs posted prohibiting the deposit of trash in the vault. It is likely that composting would be hindered under these conditions.

Incineration

Incineration is a form of waste treatment in which heat is used to oxidize waste completely, reducing it to ash. It is fast, eliminates odor and most diseases, and it is complete, requiring no further waste treatment. O&M requirements are simply an occasional emptying of the ash collection tray. However, energy requirements are relatively high. An all-electric unit capable of handling the needs of 12 people consumes 936 Watt-hours of energy with each use. Another drawback is the system's inability to handle plastic items or highly flammable substances which can damage the incinerator and create a possible hazard to the user.

This investigation determined that an incinerating system would be especially inappropriate in Army training areas because of (1) prohibitive energy costs, and (2) the system's inability to handle certain types of litter, particularly live ammunition which can explode if placed in the toilet. (The possibility of live ammunition being introduced into waste vaults was not realized until this investigation's second visit to Fort Polk when, after pumping vaults located on firing ranges, a number of live rounds were discovered along with other debris.)

Chemical Disinfection

Chemical disinfection is the principle upon which the portable toilets commonly used on construction sites operate. The chemical additives (bacteriacides) kill all forms of bacteria in waste, thereby eliminating odors and diseases. These units have the same pumping requirements of vault toilets of equivalent size because there is no actual breakdown of waste organics, and no reduction in waste volume. However, the major drawback to this system is that its bacteriacidal chemicals reduce the bacterial population of the activated sludge or trickling filter of sewage treatment plants, thereby hindering the plant's treatment efficiency.

Because a chemical system achieves neither reduced waste volume nor increased waste treatability, the two primary objectives of the desired system, it was rejected as a suitable test system.

Mechanical Aeration

Mechanical aeration is a waste treatment process in which the waste is agitated, so the surface layer is continuously being replaced by material from below, allowing all the waste to contact the air intermittently. When air is supplied to waste, the bacteria naturally occurring in it will benefit (aerobic). If waste is allowed to sit undisturbed, oxygen is available only to a thin surface layer through the mechanism of diffusion, leaving the remainder of the waste to become septic (anaerobic). Both organisms reduce waste volume; however, aerobies produce carbon dioxide (CO_2) and water (H_2O), while anaerobies produce methane (CH_4), hydrogen sulfide (H_2), and carbon monoxide (CO). Supplying sufficient oxygen through agitation will reduce waste volume and also eliminate undesirable end-products of anaerobic decomposition.

Mechanical aeration is finding increased usage in the livestock industry. Research at the University of Illinois[7] has shown that a type of mechanical aeration system known as an oxidation ditch is a workable means of treating livestock waste and requires relatively little energy and maintenance.

Bubble Aeration

Bubble aeration differs from mechanical agitation in that air is forced through pipes to the bottom of the waste and allowed to bubble up through to the surface. Diffusion occurs at the surface of each air bubble rather than at the surface layer of the waste. Aerobic digestion occurs as with mechanical aeration but at a faster rate for a given power input due to more efficient oxygen transfer.

Bubble aeration is already in use in latrines on a trial basis at Benbrook Reservoir, Fort Worth, TX. When Benbrook Reservoir was visited by this investigation, all aerators appeared to be working well. Power demands were small, no additional water was needed as long as the latrines were in regular use, and O&M requirements were minimal. Though no published report is planned by the Fort Worth district, some of their findings will be included in this investigation's final report.

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[7] D. L. Day, et al., *Livestock Waste Management Studies* (University of Illinois, College of Agriculture, July 1970).

Results

The two aeration systems were determined best suited for the treatment of vault toilet waste because they were simple, safe, achieved reductions in odor and waste volume, and could be installed as a retrofit to existing vault toilets. Both the mechanical and bubble aerator will be tested to compare their respective cost, ease of installation, power consumption, and waste treatment effectiveness.

An additional system was designed to test the application of an alternate energy source to waste treatment in remote areas. This system consisted of an electrically driven bubble aeration system, assisted by a wind-powered auxiliary compressor. Comparison of electric power consumption to that of the all-electric system will indicate how much power was supplied by the wind.

Solar Energy was also considered as an alternate energy source. However, no practical means of applying it to waste treatment could be determined. Waste aeration requires some form of mechanical energy, which is difficult to derive from the sun.

An environmental engineering firm has recently developed a vault toilet which uses solar energy to supply heat which aids in composting the waste.* This system appears promising and is being tested at various locations in the United States.

*Ecos, Inc., Boston, Massachusetts.

4 SYSTEMS DESIGN

Electric-Powered Bubble Aeration System

To properly size the bubble aeration systems, samples of vault waste were tested in water-to-waste-dilution ratios of 10:1, 5:1, 1:1, and 0:1 (full strength) in an attempt to ascertain what effect concentration has on oxygen uptake rate (OUR) and therefore biological activity. The OUR was determined by placing each dilution in a separate chamber and aerating each to saturation for a period of 30 days. Each day, the air was shut off and the dissolved oxygen (DO) level was measured once each minute for 15 minutes using an electric DO meter. The maximum OUR over the 30 day experiment was 8 mg/L/hr and occurred in the full strength sample, which consistently displayed a higher biological activity level than the 10:1, 5:1, and 1:1 dilution ratio samples. Therefore, this investigation determined that dilution of vault waste would not be necessary to assure efficient aerobic digestion in a bubble aeration system. An OUR of 8 mg/L/hr was a adopted as criterion for the design of systems to be constructed for field testing.

The air-flow rate required at an assumed oxygen transfer efficiency rate of 2 percent* and a waste volume of 160 cu ft (4530 L) was calculated to be 5.5 cu ft/min (155 L/min) at standard temperature and pressure (STP). To insure constant aerobic conditions, an aeration rate of 8 cu ft/min (226 L/min) at 5 psig (1.34 atm) was selected.

A compressor driven by a 0.6 hp (0.4 kW) motor is required to maintain the design air supply, but rather than have the unit run continuously, this investigation used a larger compressor and motor in conjunction with a high-pressure holding tank. In this way, varying air flow rates could be bled continuously from the tank at a low pressure, while the electric unit would run only when needed to restore tank pressure. This investigation used a 1 hp (0.7 kW) motor to drive a two-piston, single-stage compressor rated at 6.0 cu ft/min at 40 psig (170 L/min at 3.7 atm) which was in turn connected to a 22 gal (83 L) storage tank with an automatic preset switch which turned the compressor on when tank pressure dropped to 90 psig (16 atm) and off when it reached 120 psig (9 atm). By oversizing the system in this way, the compressor ran less often and for shorter periods, thereby extending its service life.

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*Assumed by this investigation due to shallow (3 ft [0.9 m]) vault depth.

Air drawn from the tank was distributed to the waste by a 0.75-in. (1.90-cm) diameter PVC pipe in which 0.125-in. (0.318-cm) holes had been drilled at 2-in. (5-cm) intervals (Figure 3). Piping was positioned 4 in. (10 cm) off the floor and 6 in. (15 cm) from one wall in order to induce, by rising air bubbles, a rolling motion to the waste, thus enhancing circulation of suspended solids.

Wind-Powered Bubble Aeration System

The hybrid wind/electric-powered system was essentially the same as the system described above, but with the addition of a wind-driven air compressor to act as an auxiliary compressed air supply (Figure 4). This system was designed with the intention of evaluating wind energy as an alternative power source for application to waste treatment. Wind power would be useful in remote areas where vault toilets are located far from electric power sources as well as in developed areas where it can reduce costs and conserve energy.

The wind turbine used was a Savonius Wing Rotor, a vertical axis rotor developed by S. J. Savonius in the early 1920's and used extensively in the late 1920's through the 1930's.[8] Further use and development decreased as interest in wind energy gave way to more consistent sources which, at that time, seemed in endless supply. Today, now that fossil fuels are becoming depleted, interest has again returned to wind energy. Results of recent studies into the Savonius rotor by Sandia Laboratories in Albuquerque, NM were used in the design of the rotor built for this investigation.[9]

This type of turbine was selected for three reasons: (1) it was a simple design, requiring a minimum of technical skill to design and construct, (2) it was a vertical axis turbine which minimized tower construction costs, and (3) its high starting torque made it well suited to driving an air compressor.

The Savonius rotor consists of two hemispherical cups or buckets oriented to form a letter "S" with a small gap at the middle to allow air to flow from the pressurized bucket into the low-pressure bucket, reducing drag and extracting additional power from the wind (Figure 5a). The turbine constructed by this investigation consisted of two rotors, each 4 ft (1.2 m) high and 7 ft (2.1 m) in width across the long axis, mounted one above the other on a common shaft with the upper rotor

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[8] S. J. Savonius, *The Wind Rotor in Theory and Practice* (Savonius Co., Finland, 1928).

[9] Ben F. Blackwell, *Wind Tunnel Performance Data for Two- and Three-Bucket Savonius Rotors*, (Sandia Laboratories, July 1977).

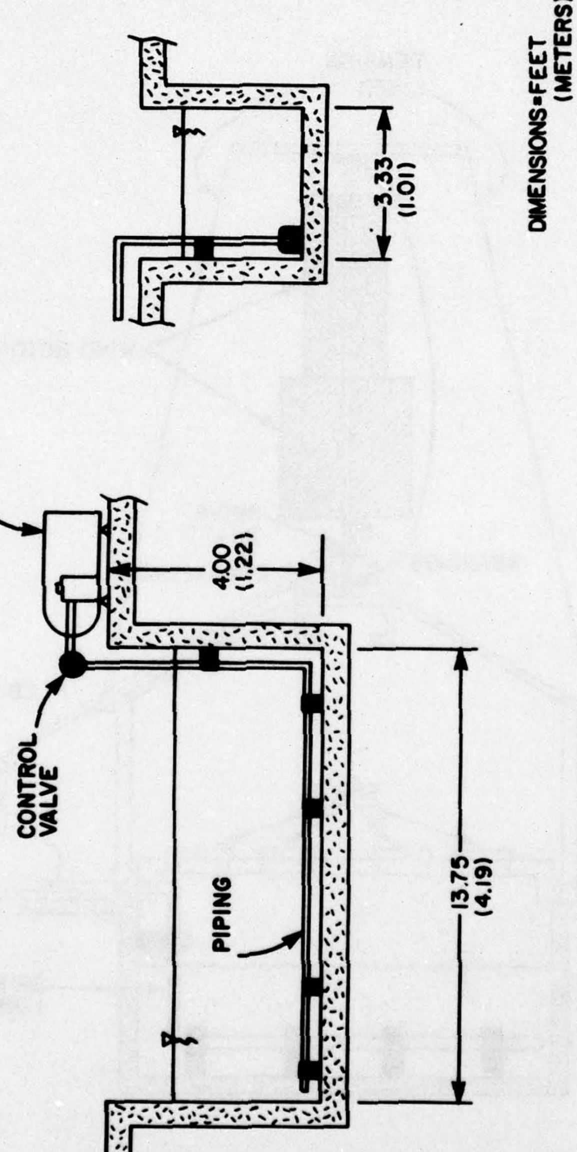

Figure 3. Compressed air aeration system.

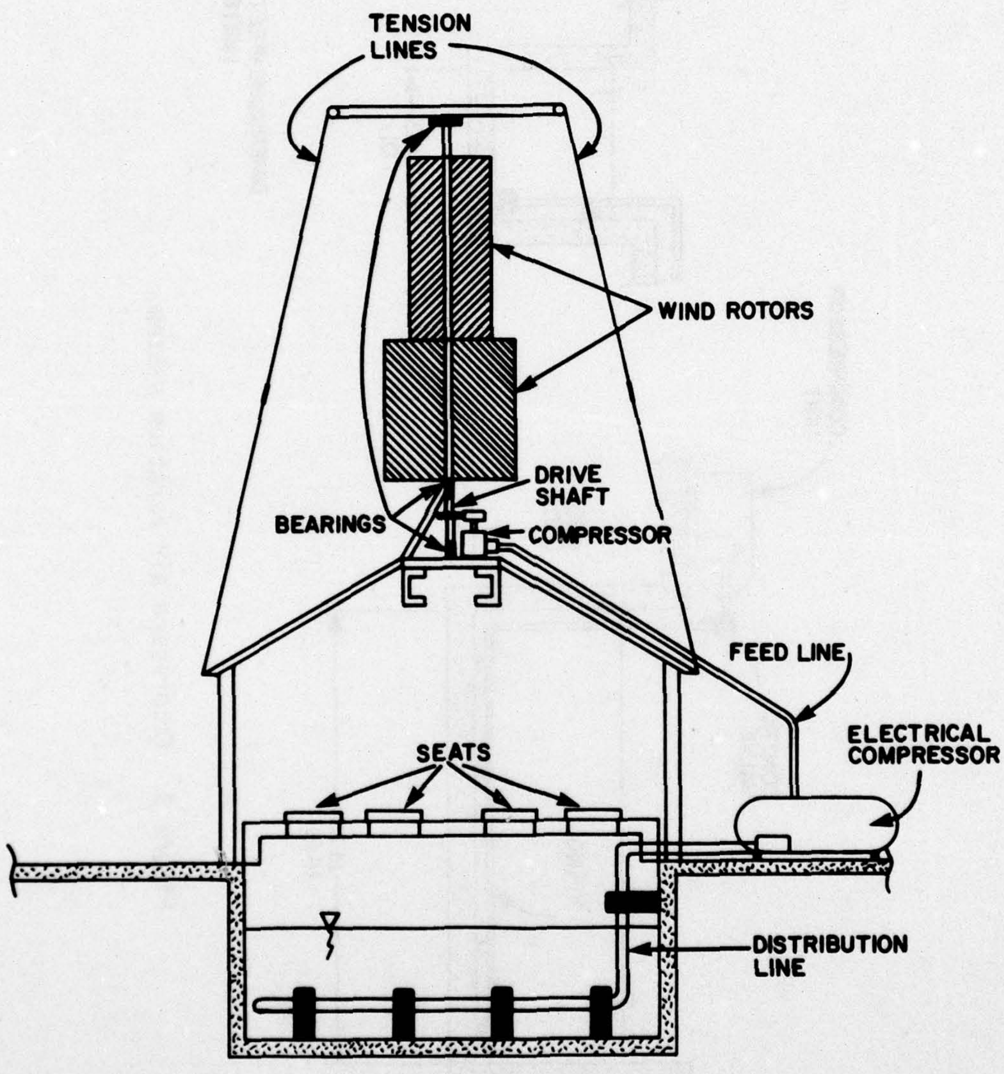

Figure 4. Wind-powered aeration unit.

rotated 90 degrees relative to the lower rotor (Figure 5b). This arrangement provides a more even torque compared to a single rotor of the same dimensions because four small impulses occur per revolution rather than two large ones. With an assumed efficiency of 30 percent[10] this turbine should produce 1/2 hp in a 15 mph (6.7 mps) wind.

The turbine shaft, supported by two bearings at the bottom and one bearing at the top, was coupled to a single cylinder, single-stage air compressor rated at 2.2 cu ft/min at 40/psi (62 L/min at 3.7 atm) when driven by a 1/2 hp (0.4 kW) motor. Power transmission from the turbine to the compressor was accomplished by two V-belts and a right angle gear box, resulting in an overall ratio of 1:4. The compressed air produced by the system was fed to the storage tank through a check valve and high pressure line. (A pressure unloader system was considered, but due to its complexity and the high starting torque characteristic of the Savonius, it was not used.) Compressed air, supplied by wind power, would be supplied directly to the aeration system, reducing the work required of the electrically driven compressor. At times of sufficient wind, the tank pressure will remain above 90 psi (7.1 atm) and the electric unit will not operate. But when the wind is low, and the tank pressure drops due to the constant bleed-off for waste aeration, the electric unit will switch on to restore tank pressure. By comparing the power consumption of this system with the all-electric system, a direct figure can be established for the power supplied by the wind.

Another test possible with this system is to determine whether wind power alone is sufficient to maintain aerobic conditions in vault waste. By turning off the electric air compressor, the wind-powered compressor will operate alone. If wind speed is high enough, often enough, the waste will remain aerobic; however, during prolonged low-wind periods, the waste would become anaerobic. If intermittent aeration reduced odor and waste volume acceptably, wind power alone will prove ideal for vault toilet waste treatment in remote areas. But if wind power alone proves impractical, auxiliary systems of gas- or battery-operated air compressors or high-pressure storage tanks might be necessary where line current is unavailable. Through an oversized wind turbine and storage tank system could probably store sufficient compressed air during high-wind conditions to maintain aeration through periods of low wind, it is doubtful that such a system would be cost-competitive with other energy sources.

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10 S. J. Savonius, "The S-Rotor and Its Application," *Mechanical Engineering*, Vol 53, No. 5 (May 1931).

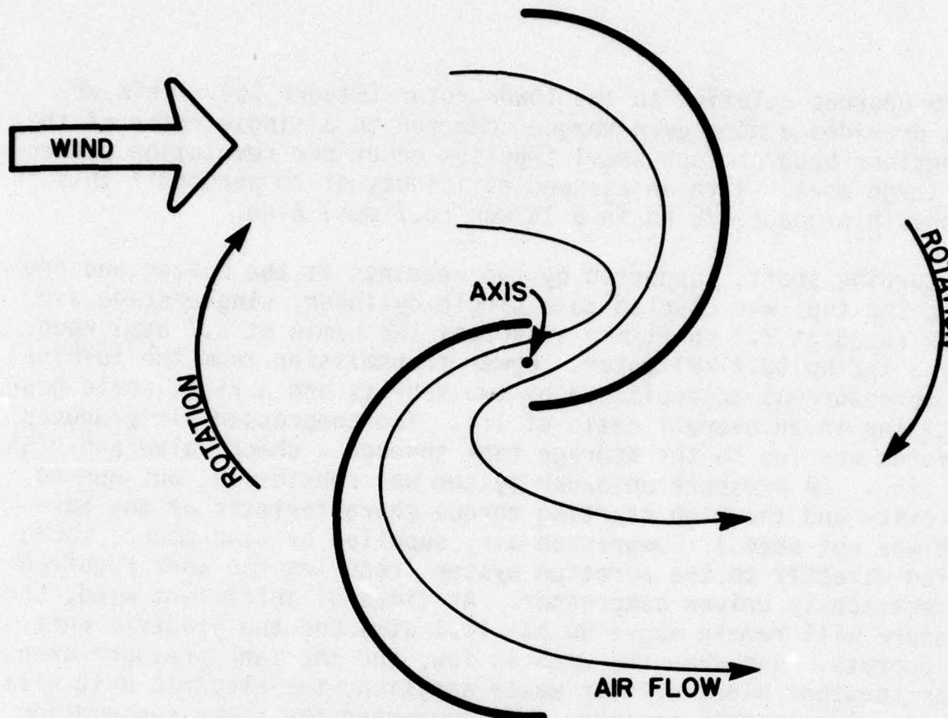

Figure 5a. Horizontal cross-section of Savonius wing rotor.

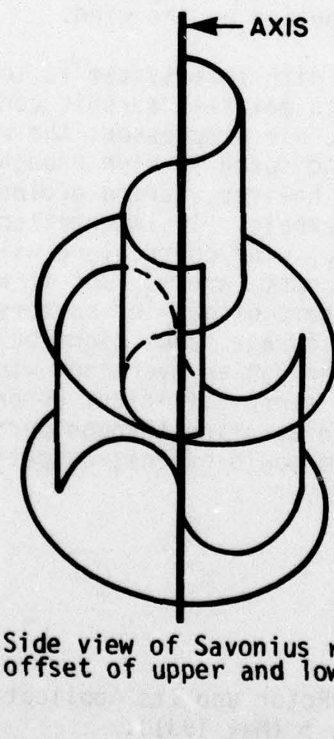

Figure 5b. Side view of Savonius rotor showing 90° offset of upper and lower sections.

Mechanical Aeration System

The mechanical aeration system consisted of a paddle mixer mounted on a vertical shaft driven by 3/4 hp (0.56 kW) gearmotor (Figure 6). The mixer had separate impellers, one fixed to the lower end of the shaft and one free to slide along the shaft, mounted on floats to keep it at the waste surface (Figure 7). The fixed impeller brought waste up from the vault bottom, and the sliding impeller forced it over the surface to the walls of the vault. This sliding impeller also agitated the waste surface to further increase air-waste contact. Allowing the upper impeller to float at the surface also insured that the amount the impeller was submerged in the waste remained constant with waste depth, thereby keeping aeration efficiency and power requirements constant. The gearmotor used had a gear ratio of 50:1, making the mixer shaft speed 30 rpm.

Results

Of the three systems, the all-electric bubble aeration system is the simplest to construct and retrofit into vault toilets because it requires a minimum of components and alterations to the latrine. The mechanical agitator is next in difficulty; holes have to be cut in the latrine, and the gearmotor and bearings have to be mounted. The hybrid wind/electric system is the most difficult because it requires the installation of an entire electric system, plus a wind turbine mount, and its associated hardware.

Costs of these systems varied widely. The electrically powered bubble aeration system is the least expensive; the only significant outlay of funds is for the compressor.

The other two systems are more experimental and require considerable fabrication. A breakdown of costs is shown in Table 1. Equipment was considered as any pre-built parts, e.g., compressors and gearmotors. Materials were defined as raw materials used in fabrication of experimental equipment, e.g., steel stock for the mechanical mixer. Labor was labor required above and beyond that of the experimentors; the cost of the more expensive systems would drop dramatically if they were mass produced.

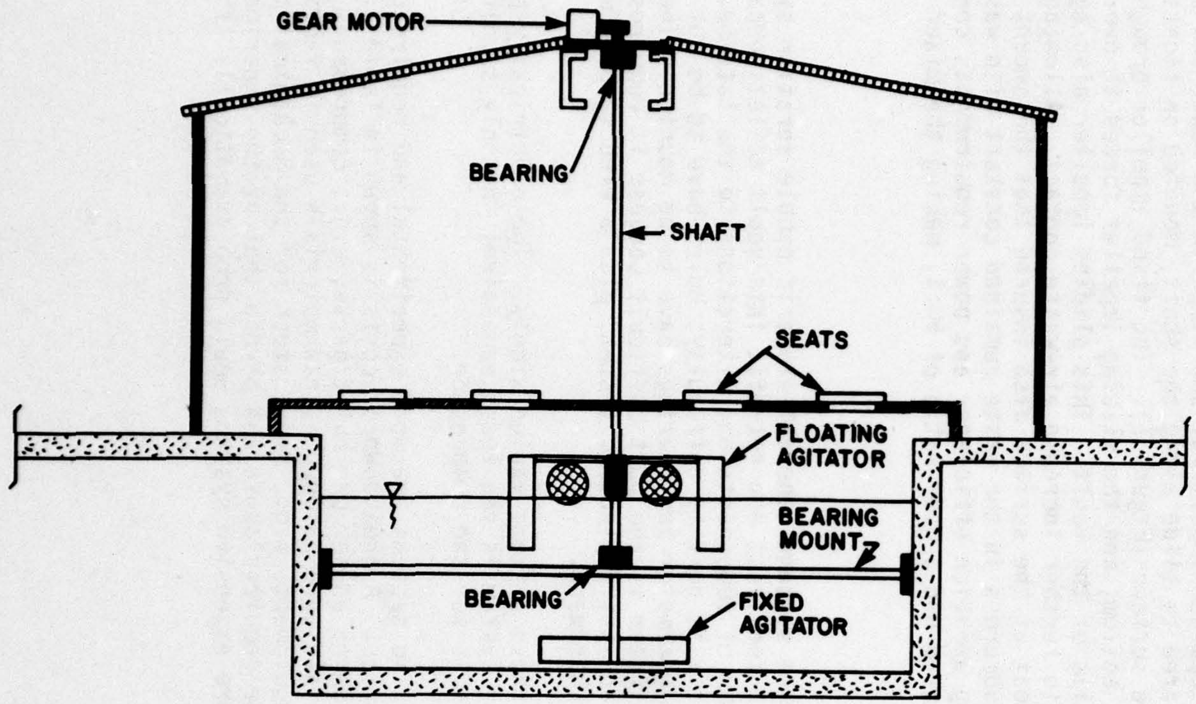

Figure 6. Vault toilet with mechanical mixer.

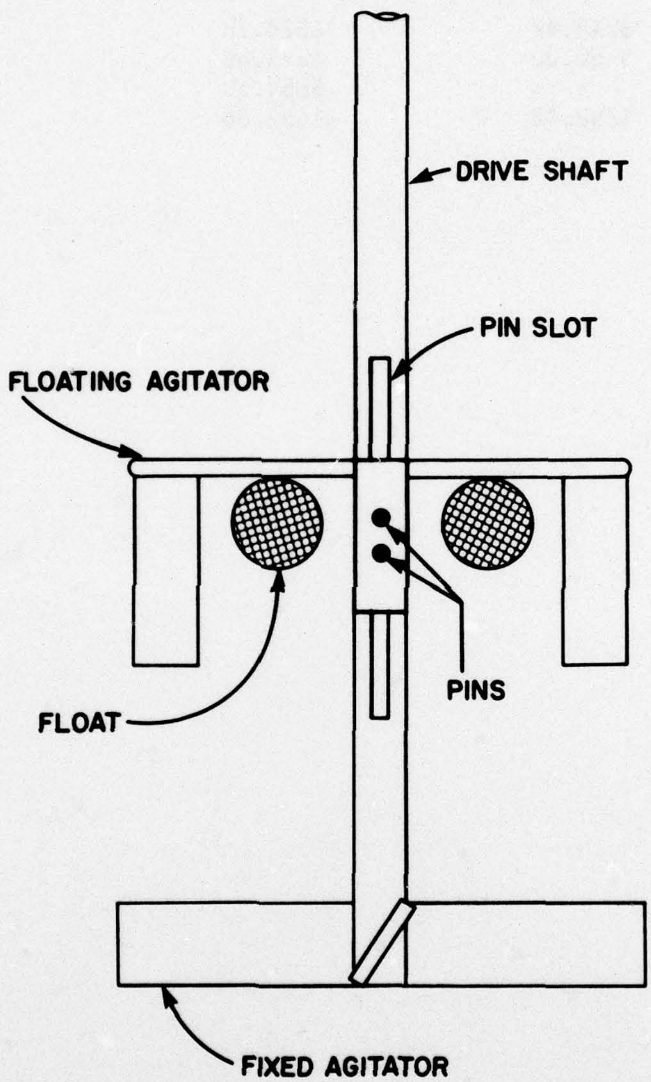

Figure 7. Detail of mechanical mixer.

Table 1

Comparative Costs of Tested Systems

	Compressed Air	Compressed Air W/Wind	Mechanical Mixer
Equipment	$242.42	$324.78	$453.11
Materials	$ 50.00	$373.60	$240.00
Labor	-	$854.50	$397.00
Total	$292.42	$1552.88	$1090.11

5 TESTING PROGRAM

A further testing program of the systems selected and constructed by the investigators of this project will be necessary to complete the evaluation of each item's efficiency in terms of both cost and vault-waste management.

CERL personnel will be required to:

1. Set the air flow rates on the compressor which drives the bubble aerators, and start the mechanical mixer. This is essentially a startup phase to clear up unforseen faults in the system.

2. Measure DO at various points in the vaults to determine how the aerators are distributing oxygen. This will be performed twice--shortly after the systems have been set up and shortly before they are dismantled.

3. Communicate maintenance instructions to Fort Polk personnel.

The duties required of Fort Polk personnel will consist of the following:

1. Routine maintenance on equipment as detailed by CERL personnel

2. Testing of each system and control on a semi-weekly basis (including BOD, SS, and DO) at a consistent point in each vault.

3. Communication of the above information to CERL personnel, along with training schedules to determine usage rates at each field site.

6 CONCLUSIONS

This investigation reviewed and evaluated various waste treatment processes including incineration, composting, chemical disinfection, bubble aeration, and mechanical agitation for application to vault toilets. Three systems were chosen, constructed, and installed for testing and detailed evaluation. These were an electrically powered bubble aeration system, a hybrid wind/electric-powered bubble aeration system, and an electrically powered mechanical agitation system.

Based on this research, the simplest and least expensive system, in terms of construction, is the electrically powered bubble aerator. Further research is underway to see how the power consumption costs of the three systems compare.

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